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Study and Automation of a Test System for Space Instrument Calibration

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UNIVERSITE PAUL SABATIER TOULOUSE III

Joint European Master in Space Science and Technology
ASTROPHYSIQUE : Techniques Spatiales et Instrumentation

MASTER THESIS

STUDY AND AUTOMATION OF A TEST SYSTEM FOR SPACE INSTRUMENT CALIBRATION

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ABSTRACT

Nowadays the independency of systems is a valuable requirement due to its implications in saving cost and time. Systems that are constantly dependent on an operator for their survival are outdated. Everyday more users demand from a system to be autonomous, robust and reliable. This was the need found at the CESR laboratory. A test system, used for space instrument tuning before launch, needed to be manually manipulated. This resulted in the operators' time loss and long duration of instrument calibrations.

Through this work a program for the automation of a calibration test system from the CESR (Centre d'Etude Spatiale des Rayonnements) was developed and added to improve a previous version. The test system is used to tune space instruments before launch. The main parts of the system are an ion beam, a mass spectrometer, an ion detector and a vacuum chamber. The configuration of the system includes some of the next features: on/off of the beam, tuning current intensity, positioning the ion beam or the instrument located in the chamber, data handling, data saving, reading of the configuration parameters, etc.

LabWindows/CVI, National Instruments programming software, was used for generating the program. Connections between the system and the PC were done either through two RS232 serial ports (COM1 and COM2), or through two National Instrument acquisition cards connected to the PC.

Overall study of the system was needed. An extensive revision of the work done for the automation of the system was done in order to suggest modifications in some malfunctions, and to add new features. Modifications were made to the existing version to improve its performance. New functionalities that control different motors in the system were developed. And finally, the full program was integrated for future use. A full documentation was developed in parallel to the work for further reference.

A program resulted that can configure the system to a given state and independently realize different desired scans to an instrument located in the chamber. The motion of the instrument, the beam, and the step between each position for consecutive scanning can be given. The intensity of the current in the filament of the ion beam can also be varied.

This report shows the different stages of the project and the background needed to develop it.

To my parents who never limited my dreams.
To Pepe, Ana Luisa and Juan Pablo who are my dream mates.

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INDEX

1. INTRODUCTION..... 4
1.1 The CESR - *Centre d'Etude Spatiale des Rayonnements*..... 4
1.2 Low Energy Test System 5
1.3 The Project 6
1.4 LabWindows/CVI 7
2. OBJETIVES
2.1 General Objective 8
2.2 Specific Objectives 8
3. BACKGROUND INFORMATION
3.1 System Description 9
3.1.1 Ion Source 9
3.1.2 Mass Spectrometer 10
3.1.3 Ion Detectors 11
3.2 System Command 11
4 LCPB – Logiciel du Commande du Petit Banc 14
4.1 LCPB – Previous Version 14
4.1.1 Current in the Filament..... 16
4.2 IP28 – PC Communication..... 18
4.3 Motors Command Software..... 20
4.3.1 The Movement of the Motors 22
4.3.2 Scan Routine..... 22
4.3.3 Security Features..... 24
4.4 LCPB – New Version 26
5. CONCLUSIONS 27
6. FUTURE WORK 28
7. GLOSSARY 29
8. REFERENCES 30
A. ANNEX I 31

1. INTRODUCTION

Nowadays, the functional independence of a system is a valuable feature due to its implications in lowering costs and saving time. Systems that are constantly dependent on an operator are outdated. Everyday more users demand from a system to be autonomous, robust and reliable. In the CESR laboratory, a test system, used for space instrument tuning before launch, has to be manually manipulated, which inevitably results in a loss of time for the operators and long duration of instrument calibrations.

This section consists of a general description of the laboratory in which the project was developed, as well as descriptions of the project and the programming software used. For further information, refer to the following sections.

1.1 The CESR - *Centre d'Etude Spatiale des Rayonnements*

The project was developed at the CESR, a space astrophysics laboratory located in Toulouse, France. This research institute belongs to the CNRS (*Centre National de la Recherche Scientifique* – National Center of Scientific Research) of France and the University Paul Sabatier. It is attached to the research units of *Physique Chimie et Automatique* and the *Observatoire de Midi Pyrénées* of the University.

The missions of the laboratory include astrophysics and astrochemistry research, the development of space instrumentation, the training of personnel and the dissemination of knowledge. It is organized in three scientific and technical departments, according to the study fields:

- Solar System (space plasmas and planetology)
- High Universe Energies
- Cold Universe

During my stay in the laboratory I joined the Solar System Department. The studies in this department are focus on two main fields: the study of the ionised environment of the planetary, interplanetary and hemispheric environments, and the study of the surfaces and atmospheres of terrestrial planets.

The CESR plays a very significant role in European space activities, with all the development of on-board spectrometers, mass spectrometers for on-site measurements and teleobservation of surfaces with gamma instruments.

In order to study and calibrate the performance of the spectrometers or ion/electron detectors, the Solar System department has two test systems. They are classified according to their working energies as follows.

- High Energy Test System
    - Ion beam: 1keV – 10keV
    - Electron beam: some eV – 10keV

- Low Energy Test System
    - Ion beam: some eV – 800eV

It is for the Low Energy Test System which the automation presented in this work has been carried out.

1.2 Low Energy Test System

The test system is mainly composed of an ion beam that generates particles to be detected, and a vacuum chamber where the instrument to be calibrated is placed. The low pressure (10^{-6} mbar) inside the system is needed to verify the performance of the ion detectors (space instruments) that have to be tested. These pressure levels are also needed to operate with the detectors used inside the instruments (micro channel plates). In Figure 1.1 the complete system is presented.

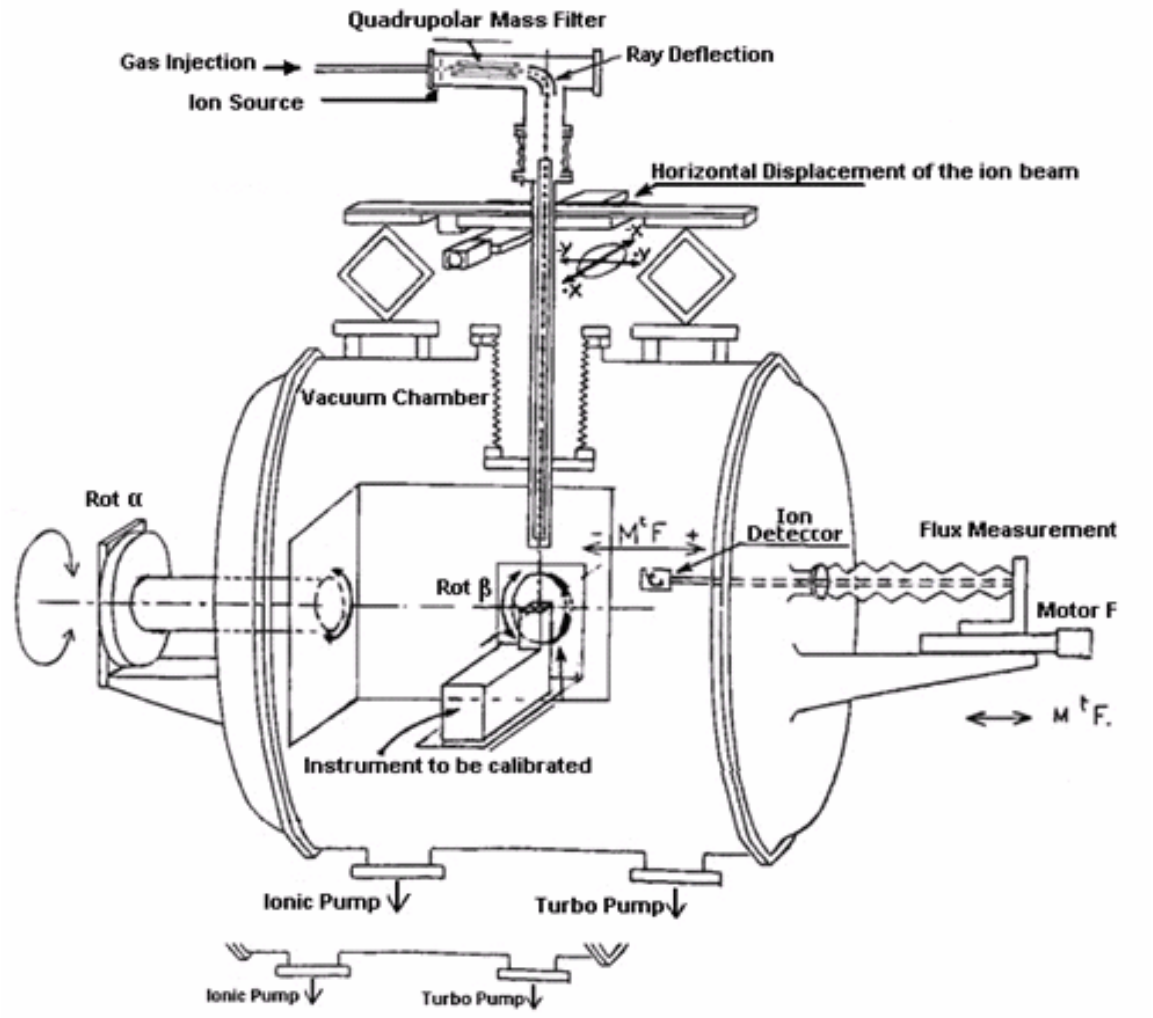


Figure 1.1 Low Energy Test System

As can be seen the beam, the ion detector (Faraday detector) and its electronic control devices are placed at the top of the vacuum chamber. To

create the vacuum inside the chamber, three pumps are located under the chamber. The required vacuum is achieved as follows:

- Primary pump is used to get an average of 10 mbar.
- Then the secondary pump decreases the pressure down to $2x10^{-6}$ mbar.
- The Ionic pump is activated when the pressure is around 10^{-5} and decreases the pressure close to $8x10^{-7}$ mbar.

The instrument that has to be calibrated is located inside the chamber. The types of instruments that are calibrated in this system are ion analyzers that will be on board spacecrafts. For tuning the instruments, different ion species, energies and directions can be set.

The system has, as shown in Figure 1.1, five displacement motors (3 translations and 2 rotations). Two of them allow the horizontal translation of the beam with respect to the vacuum chamber (x and y). This motion locates the ion ray in the desired position with respect to the instrument that is inside the vacuum chamber. The instrument is fixed with respect to its translational axes, but has two degrees of freedom in its rotation motion (α and β), which makes it possible to obtain the desired inclination of the target with respect to the ray. Finally one last motor locates a flux measurement device in the ion ray trajectory. Its displacement is in the y axis. This ion detector can be moved in or out of the trajectory with a motor F shown on Figure 1.1. It is used to observe the ion ray on an oscilloscope to verify the ion beam (intensity and shape) arriving to the entrance of the instrument that has to be calibrated.

1.3 The Project

For several years the test system was commanded by two different PCs with MS-DOS operating systems and programs based on Pascal language. With the development of new technologies and solutions from the industry, the old configuration became inefficient and outdated. The need for better system performance and autonomy was evident, and the automation of the system started two years ago.

The hardware configuration was the first step for the automation of the system. Hardware changes were done to implement the connections between the different controls from the system and the new PC with Windows XP operating system. Changes in the electronics were also done allowing the possibility for the user to choose between manual or automatic manipulation of the different controls. An improved layout of the electronic circuit of different special commands in the system was built.

After this, the second stage of the automation was the development of a primary program to control the main features of the ion beam. The program had an interface allowing the user to modify different variables of the beam, and also the possibility to launch a scan of the ion ray to identify the elements present in it.

The work presented here is the third stage of the automation of the system. At first a study of the old program was done in order to improve

features and modify some malfunctions that were found. This helped to become familiar with the software used for developing the program - LabWindows/CVI that allows programming in C++ with a friendly environment. The continuation of the automation was also kept updated. A new program was created to control four motors located in the system and to enable the launching of scanning routines when the calibration of a space instrument is required. A full documentation was developed in parallel to the work for further reference.

The final goal in third stage of the system automation was a program that can configure the system to a given state and independently realize different desired scans to an instrument located in the chamber. The motion of the instrument and the beam as well as the step between each position for consecutive scanning can be given. The intensity of the current in the filament of the ion beam is also a variable of the system that can be modified with the program in the scanning routines.

Further work can still be developed to achieve a fully independent system and improve the performance of the existing one. This is presented in Section 6.

1.4 LabWindows/CVI

National Instruments LabWindows/CVI is a software development system for ANSI C programmers for test and measurement applications that greatly increase the productivity of engineers and scientists. It is used to develop high-performance, stable applications in the manufacture, military and aerospace, telecommunications, design validation, and automotive industries. It contains an interactive environment for developing programs and libraries of functions for creating data acquisition and instrument control applications. LabWindows/CVI contains a comprehensive set of software tools for data acquisition, analysis, and presentation. It has an interactive environment for editing, compiling, linking, and debugging ANSI C programs. The programs written in the LabWindows/CVI interactive environment must adhere to the ANSI C specification. In addition, different tools can be used: compiled C object modules, Dynamic Link Libraries (DLLs), C libraries, and instrument drivers in conjunction with ANSI C source files when developing programs. The power of LabWindows/CVI lies in its libraries. The libraries have functions for developing all phases of data acquisition and instrument control systems [1].

2. OBJECTIVES

2.1 General Objective

The main aim of this work is to continue the automation of the calibration test system of the CESR used for tuning space instruments.

2.2 Specific Objectives

- Get vast knowledge of the test system in order to understand its functions.
- Study the hardware connection of the system with the PC.
- Learn the use of LabWindows/CVI.
- Study the program code of the LCPB (Logiciel de Command du Petit Banc).
- Revision of previous work done for the automation of the system.
- Check for modifications that can be done or need to be done in the previous work.
- Make changes and respective tests of the system.
- Develop the program that controls the motion of the motors of the system.
- Test and improve the program for better performance.
- Add a new program to the existing one.
- Overall test of the system.
- Write a user manual for the new part.
- Document the algorithm used for the different parts of the programming, for future modifications of the code.
- Show the features of the new program to the future user.

3. BACKGROUND INFORMATION

3.1 System Description

The ion beam consists of an ionization chamber, mass spectrometer, Faraday detector and instruments for controlling the devices. Usually it is used for gas mix analysis (molecule content and proportion in a mixture). Its different working stages are: injection of gas, ionization of the gas, and mass selection by the quadrupole mass spectrometer also called mass filter, and the measurement of the selected ions.

3.1.1 Ion Source

The ion source contains two rhenium filaments (main and redundant). The filament is the system cathode of the electrons accelerometer. The current through the filament can be in the range of values from 70 to 600 μA. The filament is warmed up and placed in a lower potential of the one of the gas that will be ionized. The high temperature allows the ejection of some electrons from the filament, and the differential potential accelerates them towards the chamber containing the gas to be ionized. The emitted electrons will have energy of 70 eV at the moment when they arrive to the chamber containing the residual gas. This potential is found between the Wehlnelt electrode and the ionization chamber. The collision of the electrons with the gas particles leads to the ionization of the gas. The ions will be extracted through the diaphragm that produces in the chamber a weak electric field that will pull them out. The lenses will focus the ions that will arrive to the mass filter for the ions selection. The spectrometer exposes the ions to high frequency electric fields crossed in a way that only the ions with a certain relation mass/charge will go through. The selected ions will be accelerated to the output of the spectrometer by a potential difference of 0 V to 800 V. The resulted ion beam can be either reflected towards the vacuum chamber, so the space instruments can be tuned, or pointed to the Faraday detector, so an analysis of the ions in the beam is done. In Figure 3.1 the ion source structure with its parts can be seen [6, 8-10].

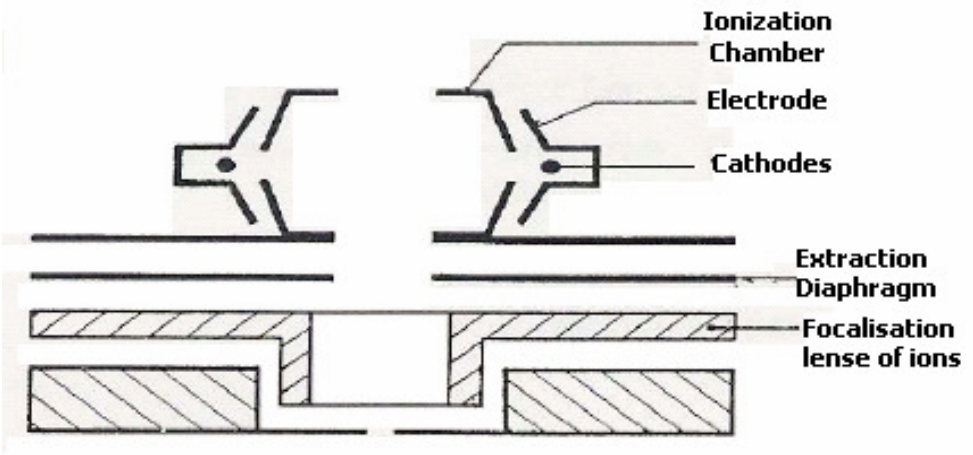


Figure 3.1 Ion Source

The potential difference between the electron collision chamber (were the ions are created) and the ground is higher than the potential difference found between the electron collision chamber and the ion source (cathode). As a consequence, the cathode has a positive potential with respect to ground. To ensure that the ions are stopped in the mass filter to the required energies, few eV, the average potential of the mass filter should be some eV lower than the one in the electron collision chamber.

The advantages of this system are:

- the cathode has a positive potential with respect to the mass,
- the ions remain just a short time in the field transition zone between the ions source and the mass filter.

As previously mentioned the ions can be accelerated towards a Faraday detector or deflected towards a vacuum chamber. In both configurations the ions will be forced to follow a curve trajectory, in order to avoid non charged particles to arrive to any of the detectors (Faraday or any instrument located inside the chamber). These non charged particles can come directly from the ionization chamber or also be old ions that regained an electron, which, as they are not charged, can go through the spectrometer. The beam must be deviated for detectors sensitive to non charged particles, because they can generate undesired noise. For the Faraday detector the ion ray has to be turned between the spectrometer and the entry of the detector. This function is done thanks to an electric field that also prevents non charged particles to arrive to the detector. For the instruments inside the chamber, the system configuration is used to turn the beam to send the ions towards the vacuum chamber following a trajectory of 90° from the ion filter.

3.1.2 Mass Spectrometer

A quadrupolar mass spectrometer is used as mass filter for the ions. It allows the selection of ions according to their mass (from 0 – 100 amu). The mass filter is formed by 4 cylindrical electrodes. The accurate layout of the rods is really important for a good performance of the device (mass filtration, stability and sensitivity). A high frequency variable tension and a constant one are applied to the rods. The oscillation characteristics of the ions in the electric field will cause that only the ions with the wanted mass/charge ratio will pass through the filter, while the other ones will be rejected out of the rods. Figure 3.2 shows a quadrupolar mass spectrometer.

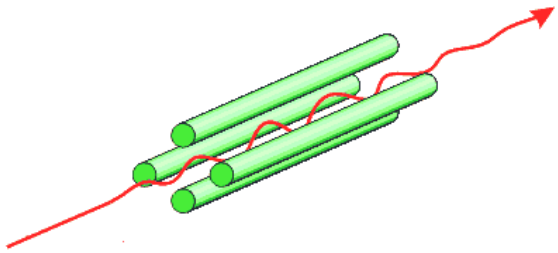


Figure 3.2 Quadrupolar Mass Spectrometer [2]

3.1.3 Ion Detectors

In order to analyze the ions produced by the ion source and selected by the mass spectrometer, there is the option to send the ion beam to a detector. In the CESR system there is the possibility to send the ions beam towards a Faraday detector. The Faraday collector is composed of a circular disc of conducting material. The ions arrive at this target and transfer their charges as an electrical current. This current is then amplified by the system electronics for the processing of the information.

The other trajectory that the ion ray can take is toward the vacuum chamber where the instrument to be calibrated is placed. If the vacuum is not low enough there is a high possibility that the ions will not reach the target due to the high probability of collisions with particles found in their path. The vacuum should be lower than 1.3 10^{-6} mbar.

Figure 3.3 shows whole diagram of the system, including the ion beam, the mass spectrometer and the deflector.

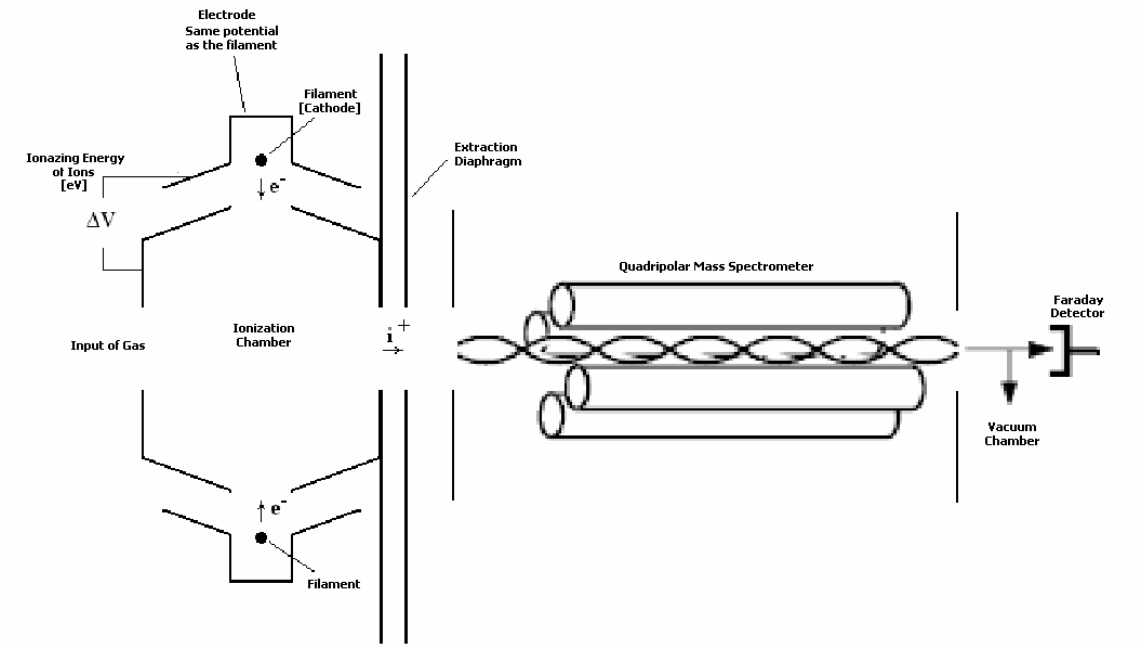


Figure 3.3 Ion Beam System

3.2 System Command

For commanding the overall system there are different devices: the QMS-420 that controls the ion beam system (ion source, mass spectrometer, and Faraday detector), the TL 78 that controls the motors of the system, the high voltage source for accelerating the ions and finally an electronic box that was built for modifying also some variables of the ion source. These devices work as manual user interfaces for the different parts of the system. The user has direct access to all of them. Figure 3.4 shows the system control layout. All these devices are located in a rack of the Low Energy Test System in the control room. There are also devices controlling

the ion detector located inside the vacuum chamber. They are also located in the command rack.

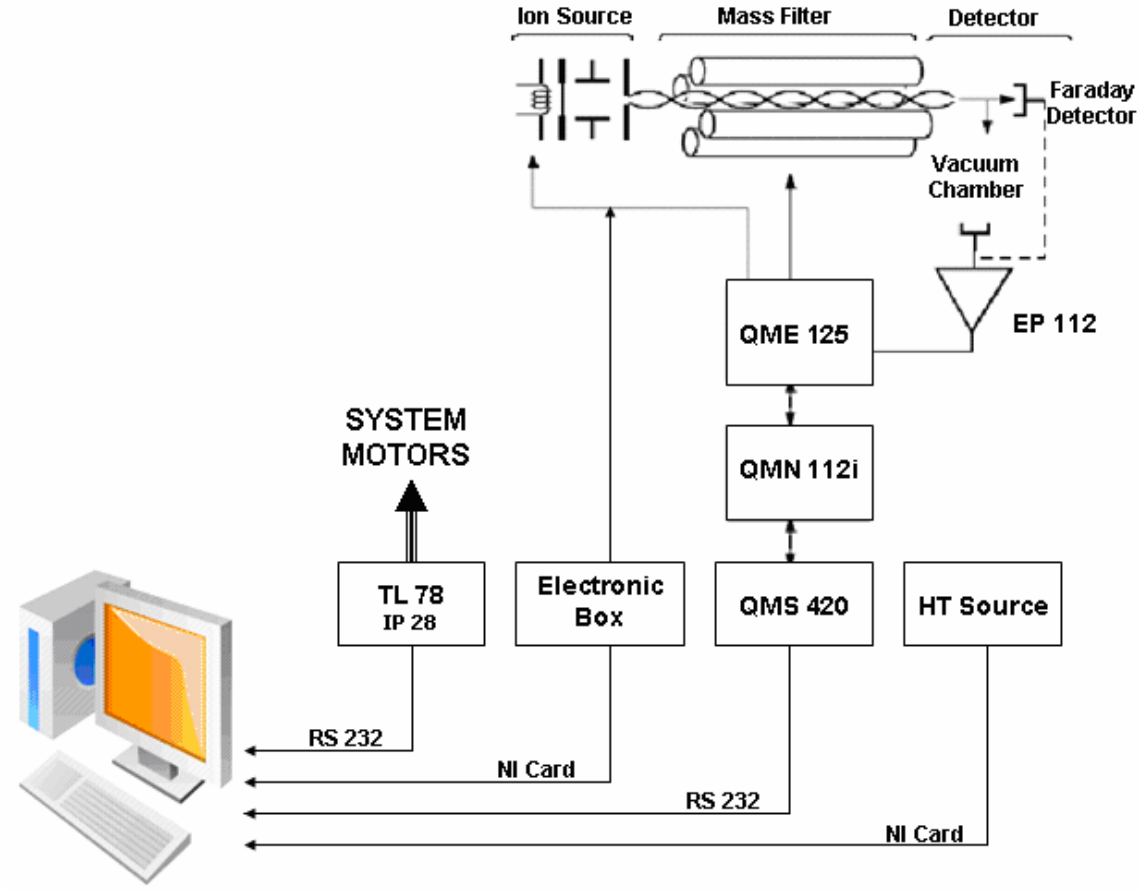


Figure 3.4 System Control Layout

The QMS-420 is the direct control interface for the ion source. It can be accessed directly by keys on its front panel, or by a PC connected serially through a RS232 interface line. It is connected to other systems that process the signals from the ion beam. These systems are the QMN-112i, the QME-125 and the EP-112. The QMN-112i amplifies the signals coming from the QMS-420 and from the system towards the PC through the QME-125. It works as an isolated link between these two devices, and provides an interface decoupled from the ground. It allows potential difference up to 900 V between the two devices. The EP-112 receives and amplifies the signals produced by the Faraday detector and sends them towards the QME-125. And finally the QME-125 produces the signals needed by the source and the mass spectrometer. The acceleration voltage for the ions that are sent to the vacuum chamber is controlled manually, with an external high voltage source [6].

The QMS-420 has a display to show important information on the status of the system to the user, as well as errors in the system or in its configuration. With the QMS-420, changes in the current of the filament can be done, as well as the change on/off to start/stop the ionization of the gas.

As an important feature of the system a scan of the produced ion beam can be done, yielding the specific content of the ions (elements). The scan occurs in the Faraday detector. The ion beam goes through the mass

spectrometer and then towards the Faraday detector in order to get a scan of the ray. The system will set the mass spectrometer to filter ions with different masses, from 0 amu up to a given value according to the scan routine configuration. The system starts with the lower masses and the mass range given by the user. This information is processed and sent to the QMS-420 from where it can be accessed through the RS232 line.

The electronic external box located in the command rack can control the intensity of the current through the filament, the focus of the ion beam, the acceleration voltage, the manual/automatic mode, the trajectory of the ray (ion detector or vacuum chamber), and the motors end position. The electronic circuit was modified in the first stage of the automation to give the user the option of having either automatic or manual access to the system. Its outputs are connected to the PC through a NI (National Instrument) data acquisition card [9].

The TL 78 is used to generate the power signals needed to control the electrical motors located in the system. This makes it possible to control 4 motors, the translation ones of the ions beam and the ones located in the instrument rotation axis. The motor responsible for the motion of the ion detector inside the vacuum chamber is not controlled by this device, and furthermore was not automated in this work, so its control device will not be studied. Each motor can be controlled by complete turns or partial turns. The console has visualization displays of the positions of the motors, and as well as the possibility to manually manipulate them. This device can be manually accessed by the user from its frontal panel or also by a PC connected in the series RS232 line to the IP28 that directly controls the TL 78. The IP28 works as an interface for the PC, and can also program routines for the motors [5, 7].

System values can be accessed through two NI cards. In Table 3.1 the input and output variables connected to the PC at each of the different cards are listed. Note that here output means from the PC towards the electronic box, and input from the electronic box to the computer. In the table the value range for each of the variables is presented. According to the values expected each of the lines were connected to analogue (AI or AO) or digital (DI and DO) input/output from the NI cards.

Command	**Card/Channel**	**Range**	**Input/Output**
Current Emission	AO 1/1	0 – 1.8 V (0 – 600 μA)	Output
Focalization	AO 1/0	0 – 5 V	Output
Faraday / Vacuum Chamber	DO 1/0	0 – Chamber 1 – Detector	Output
End Position of Motors	DO 1/1	0 – Off 1 – On	Output
Ions Energy	AO 2/0	0 – 10 V (0 – 800 eV)	Output
Trajectory Status Faraday / Vacuum Chamber	AI 1/4	> 4V - Detector < 4V - Chamber	Input
Status Dead End of Motors	AI 1/2	> 2V Yes < 2V No	Input

Table 3.1 Input and Output of the NI Acquisition Card

4. LCPB – Logiciel de Commande du Petit Banc

The LCPB software is used to command the test system from a DELL PC with Windows XP operating system. The software was programmed in LabWindows/CVI. As mentioned in Section 3.2 connections are done from COM1 and COM2 to two RS232 cables and also through two NI data acquisition cards. These connections are for the different system equipment that control different variables through the user interface.

The LCPB was created because it offers the user a simple working environment. It allows the user to have easy and direct access to different main features of the ion source. It produces through the NI acquisition cards analog command outputs towards the electronic box located in the rack. And also it writes in the COM1 port towards the QMS-420 in ASCII. During the development of the project in the CESR the study of the old version of the LCPB was done and also some modifications. This is documented in Section 4.1.

After studying the old version of the software, a new independent version software was created to control different features that were not incorporated to the previous LCPB version. These features are, as mentioned before, the movement of four different motors located in the system for making the displacement of the ion beam on top of the vacuum chamber, and the instrument located inside the chamber. Refer to Section 4.2 and 4.3 for further information.

Finally the integration of both programs was done and is presented in Section 4.4.

4.1 LCPB – Previous Version

The LCPB was conceived out of the need for an updated user interface and a program to control some of the features of the Low Energy Calibration System. The first stage of the program was able to modify different variables through the interface between COM1 and both of the NI acquisition cards connected to an electronic box located in the rack where different parts of the system were found, to the QMS-420 interface and directly to the high power supply for the ion source acceleration tension.

The program was developed (on the basis) of the updated software used several years ago that commanded the QMS-420, but also with the observation of the data transmitted through the RS232 line using a serial logic analyzer, that experimentally shows the raw information transmitted between PC and the QMS-420 [8].

The features that can be modified with the old version of the LCPB are:

- Acceleration High Voltage applied to the ions (from 0 to 800 eV)
- On/off of the filament
- Current intensity through the filament
- Beam focus

- Selection of mass species of the ions
- Trajectory of selected ions towards the Faraday detector or the vacuum chamber
- Scan of the ray for determining the elements contained in the ionized gas
- Other different options can also be selected

In the interest of the system's security, the values for the acceleration voltage of the ions and the current intensity in the filament are limited in the interface (LCPB) to 800V and 600μA. When turning off the source, the intensity of the filament needs to be stepped down slowly to a minimum value (close to 0 A), before the user turns it off completely. The program displays messages for the user, informing of the system's status, i.e., of the beam status and when dysfunctions occur. The software provides a help document that allows the user to get to learn more about its functions and how to solve different problems.

The software allows the user to do a scan of the ion ray. The ion beam needs to be sent towards the Faraday detector. The mass filter will select one by one all the masses through the mass range selected by the user. The LPCB displays a graph in a window that shows the result obtained from the scan, where the content ions distribution through the different masses can be seen. By placing the cursor over any part of the plotted curve, information about the possible element specie is displayed. Figure 4.1 shows a plot obtained from gas ionization in the chamber and detected in the Faraday detector.

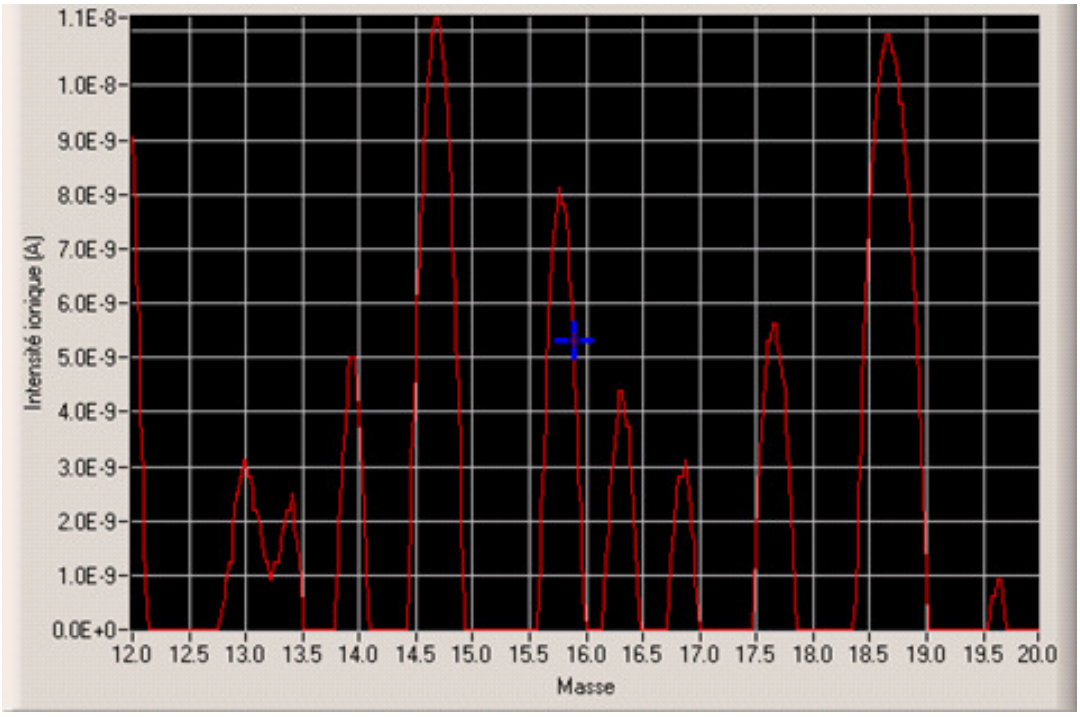


Figure 4.1 Plot of the Ion Ray Scan

A deep study of the old software was done in order to understand the interaction between the QMS-420 console and the PC. While the

programming algorithm was understood, different errors were found in the code. After a review of the errors and the general performance of the system, some corrections were recommended and changes were made to the code in order to improve the system.

This new modifications included changing variable names or values that were wrong, and are not documented in this report. However, adjustments made to certain routines which were in need of improvement are listed below:

- Enableing/Disabling buttons while the system is processing information or performing a task.
- Enabling the close button for the scan window.
- Enabling the possibility to start a scan with a zero amu mass.
- Rectifying boundary conditions for the scan.
- Erasing functions that were not used when the program is executed.
- Adjusting the value for the current in the filament.

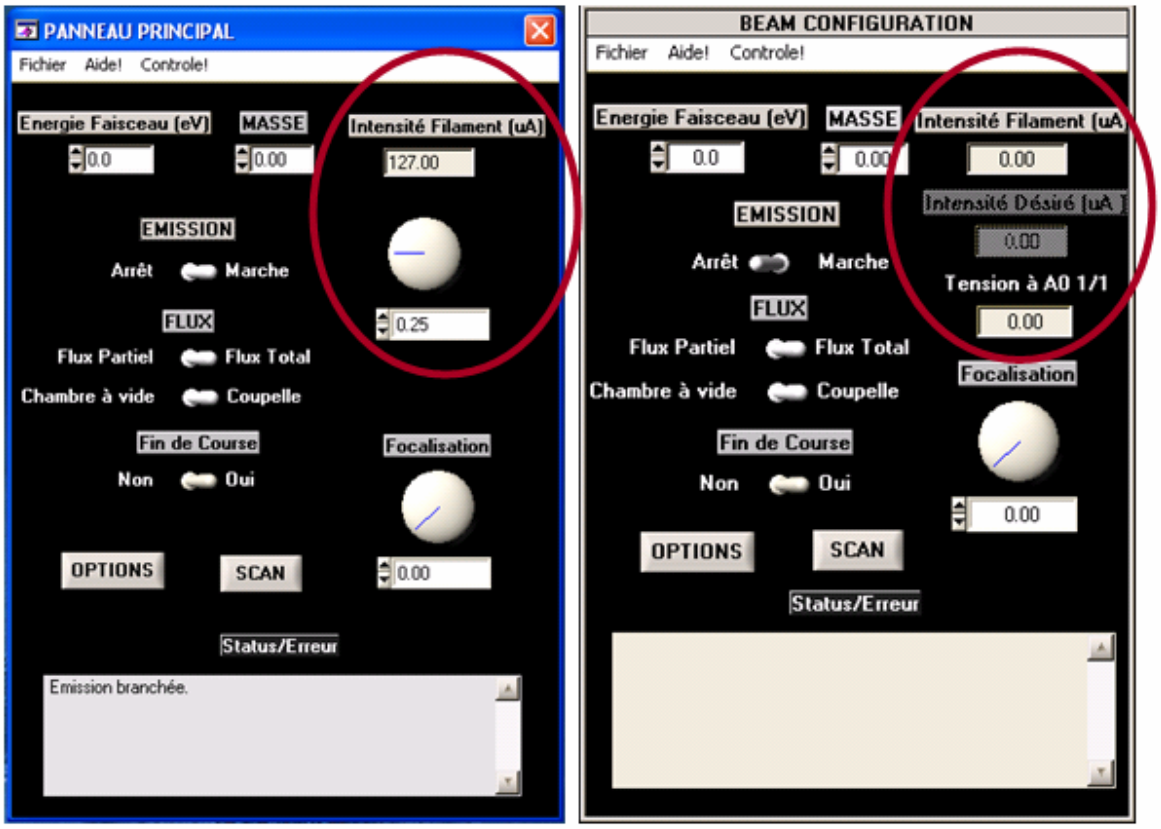
As this last change was the more important done to the system, the new algorithm implemented is explained briefly in the next section.

4.1.1 Current in the Filament

The current in the filament, which emits electrons that are accelerated for producing collisions with the gas in the ionizing chamber, can be modified in the user interface of the LCPB software. In Figure 4.2 the old and new version of the LCPB Ion Source panel are shown. The sections for the filament current values are highlighted and discussed next.

As the current in the filament can not exceed 600 μA, special care must be taken. A limit to the NI card output is set. Another important consideration that needs to be made while tuning the filament is that only small changes of current are allowed. If this is not achieved in the long term the filament can be damaged and its life time reduced.

In the old version of the LCPB the current was modified directly with one of the output of the NI card. As it can be seen in Figure 4.2 the value was changed with the help of a knob. The real value of the filament intensity was displayed in the panel and the user directly modified the voltage value of the NI card. The voltage from the NI card was electronically converted to the current intensity in the filament. Due to the delay in the port communications and the system response, the knob control was inefficient. The change in the value of the current was slow and the user could keep modifying the value even thought the updated of the last change was not displayed on the user screen. This resulted in significant changes of the values of the current without notice, and long delays in achieving a desired value. The old version did not have a special feature to protect the filament from big current changes. Small changes were monitored to be less than 30% only when the filament was turned off.



a) **b)**

Figure 4.2 Ion Beam Control Panel for the LCPB. a) Previous Version. B) Version 2007.

In the new version the value that is modified is the current. The real intensity in the filament is displayed, the desired intensity value can be entered and the actual voltage written into the NI card is shown. The voltage feed to the NI card was added to the interface for security reasons, so the user can make sure that the value in the card not exceeds 1.46 V (600 μA in the filament).

A different algorithm was developed for adjusting the value of the current in the filament for any of the different cases (turn on, turn off, value change). This algorithm is shown in Figure 4.3. As it can be seen boundary conditions and smooth changes protection were included for protecting the filament.

It was observed that the relationship between the value of the filament current and the value of the voltage in the NI card does not remain the same. It varies according to the number of times that the filament has been used (wear out) and the period the filament has been turned on (stabilizing time). This is why in the new approach the previous n-1 and the actual n current/voltage values are taken to calculate a curve that is used to obtain the next voltage value (desired) in the NI card to increase/decrease the filament intensity.

The algorithm was coded and replaced the old one of the previous version of the LCPB.

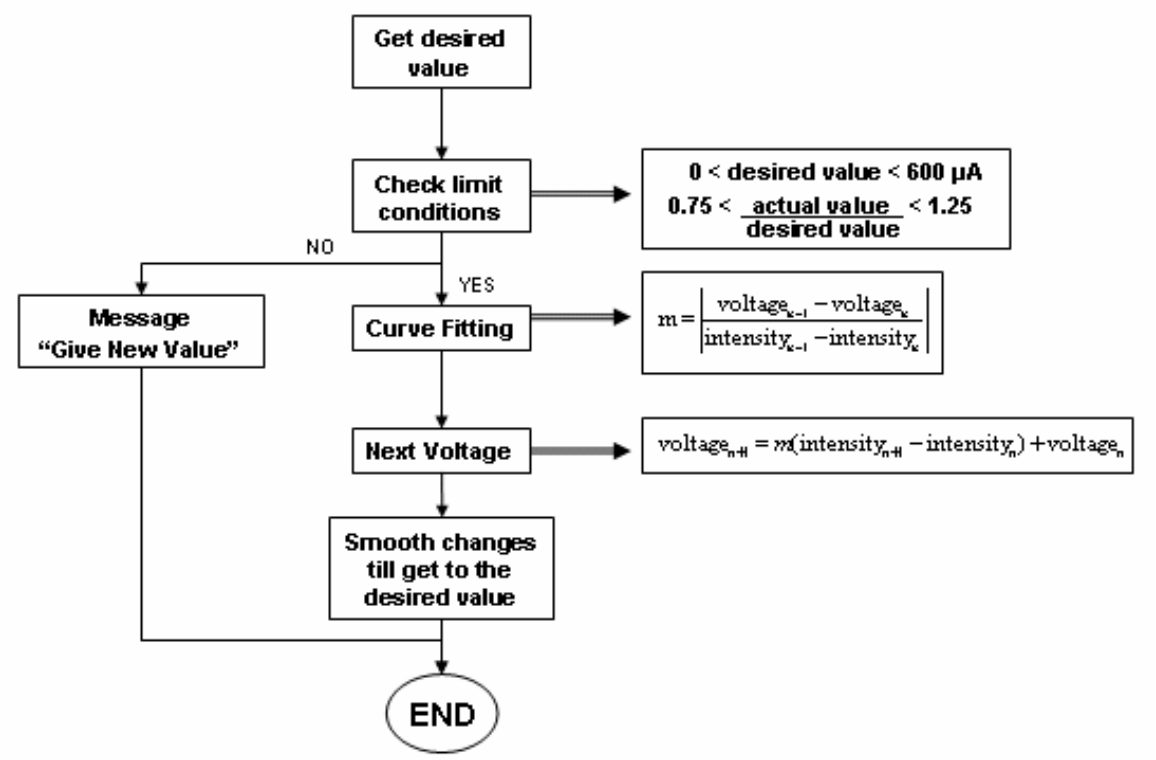

Get desired value
Check limit conditions
0 < desired value < 600 µA
0.75 < actual value / desired value < 1.25
NO
YES
Message "Give New Value"
Curve Fitting
$m = \left| \frac{voltage_{k-1} - voltage_k}{intensity_{k-1} - intensity_k} \right|$
Next Voltage
$voltage_{n+1} = m(intensity_{n+1} - intensity_n) + voltage_n$
Smooth changes till get to the desired value
END

Figure 4.3 Filament Current Fitting Algorithm.

4.2 IP28 – PC Communication

After becoming familiar with the previous version of LCPB and the programming software LabWindows/CVI, a new area of the Low Energy Test System was developed. As stated before, this stage includes the commands of four of the motors of the system.

Figure 3.4 demonstrates that the TL 78 is connected to the IP28, which creates a means of communication with the motors. Both of them can be accessed through their frontal panel or through a PC connected in series through the RS232 line. The IP28 converts the commands given by the PC or its frontal panel to signals to turn on/off the feed voltage to the different motors connected to the TL 78. The motors controlled by the TL 78 are the linear displacement of the ions beam (x and y) and the angular displacement of the instrument (α and β).

A study of existing controlling software was necessary to communicate with the IP28. This software was used to command the IP28 through a PC, and was written in TURBO-PASCAL. Through this research, it became apparent that ASCII character encoding was required for communication. Different commands, shown in Table 4.1, were already saved in the IP28 that recalled different routines for controlling the motors. Not all the routines recognized by the IP28 were used, and therefore are not presented in the table. The function of these commands was evaluated using a serial logic analyzer that also helped to understand the response of the system to the different commands. These commands were the ones used for the new software developed subroutines [7].

Command	Function
D {motor axis};	Ask the system the actual position of the motor(s).
M {motor axis};	Demands the motor(s) to move in relative motion.
N {motor axis}{nnnnnnn};	Configures the number of step to move in relative motion for the motor(s) with nnnnnnn from 1-7999999.
O {motor axis};	Look for the origin position of the motor (s)
R {motor axis}{nnnn};	Defines the motor(s) speed value for the fast mode configuration [32-4000 impulses per second] with nnnn from 32 – 4000
T {motor axis}{nnnn};	Defines the motor(s) speed value for the slow mode configuration with the period of the motor impulses [0.01-50 impulses per second], with nnnn from 2 /9999 period (nnnn times 10 ms)
+ {motor axis};	Defines a positive motion of the motor(s)
- {motor axis};	Defines a negative motion of the motor(s)
?;	Ask for the status of the system

Table 4.1 IP28 Commands Used for the New LCPB.

In order to establish a connection PC – IP28 the IP28 has to be positioned in distance mode (key in the front of the console panel). The instructions to the motor were written in the port COM2 of the PC. The communication baud rate for the PC port was settled to 9600. Odd parity was used as error detecting code for the transmission according to the configuration of the IP28.

The IP28 allows two execution modes. *Punctual* that refers to a permanent exchange between the user and the IP28. In this mode all the commands are automatically executed as soon as they are received. The other mode available is *cycle*, with which the user can elaborate a program formed by a series of commands. This program is then executed by demanding the cycle function. For the case of our application the punctual mode was used. In addition each sent command is checked for a good reception during the transmission (character check mode).

To initiate dialogue PC – IP28 several commands need to be read and sent from and to the IP28 respectably. When the IP28 is turned on it emits a signal that states that it is ready to receive data. The PC needs to read the status of the IP28 to ensure that the console is working properly, and it will then wait to receive a flawless message.

After this, different configurations of the data lines can be settled. As a default for our application, the lines were set to: no numeration in lines, only error codes are used for error detection (no error message is added), BEEP every time there is an error in the system, data is added when the commands are being executed (motors position), and each command is transmitted in the line when they are being executed.

To indicate the end of line/command, [TT] ('CR LF') is required by the IP28 system. During the communication, it adds [TR] ('CR') every time it ends sending data through the RS232 line (in this case to the PC). The data handling algorithm by the IP28 is presented in Figure 4.4. The ready state of the IP28 is given by the * as it can be seen in the figure. A valid command and its execution is given by the %, [TR] is added at the end of the line when the execution of the task is finished. For each instruction send by the PC to the IP28, it must end with ';' + [TT].

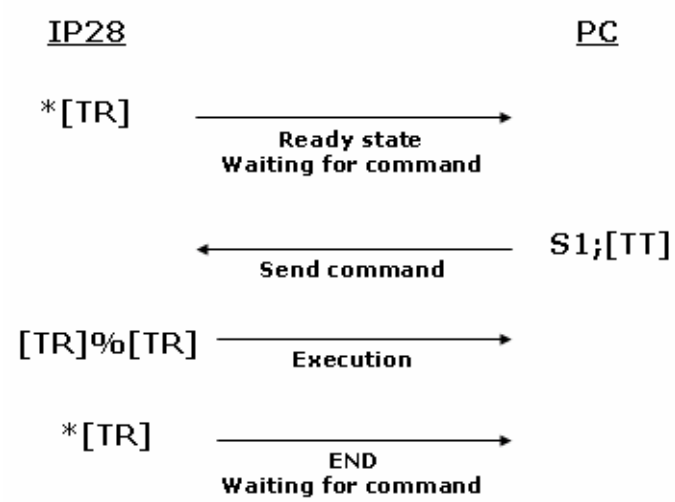


Figure 4.4 Data handling algorithm of the IP28.

Every time the IP28 receives and executes commands it checks for error. If an error is found an error signal will be emitted to the PC. If an error is detected the IP28 stops receiving commands and executing tasks, and waits for a special message that states that the problem has been solve. After receiving the message the IP28 goes to the ready state and waits for commands. In order to solve the problem, 'status' has to be invoked so the information about the problem can be read and then the problem needs to be solved. The status is updated every time a command is executed, so if there is an error, any other right command will reestablish the 00 error state (no errors).

At the start of the system, default movement variables of the motors are configured in the system. These are the following:

- Speed = 2000 impulses/seconds
- Motor acceleration curve $\rightarrow$ 400 to 4000 Hz in 300 ms.
- One turn per motor step.

It was important to understand the relation between distance and turn of each of the step motors. This was done experimentally for each of them, and it was found that for the linear motion motors 1 impulse corresponds to 0.01 mm and for the rotational motion motors 1 impulse corresponds to 1°.

After understanding the concepts of the communication with the IP28 the program was developed. In the following sections, different parts of the program are presented, including the algorithms which were necessary for many important functions within the program.

4.3 Motors Command Software

Two different situations were considered while creating the new program:

- Desired to move the beam or the instrument manually to a defined position, or to bring the motors back to their origin.

- Configuration of a scanning routine to tune an instrument located in the chamber.

These two operational modes were included in the user interface of the program. Figure 4.5 presents the main panel of the software developed. It is divided into two main parts. The left half displays the position of the motors and also has functions that can make movements of them. This side also has a display plot that shows in real time the actual position of the beam in the x and y axis. The right half is where all the parameters of a beam scan for instrument tuning can be settled. A system status window is located in the right bottom part of the panel.

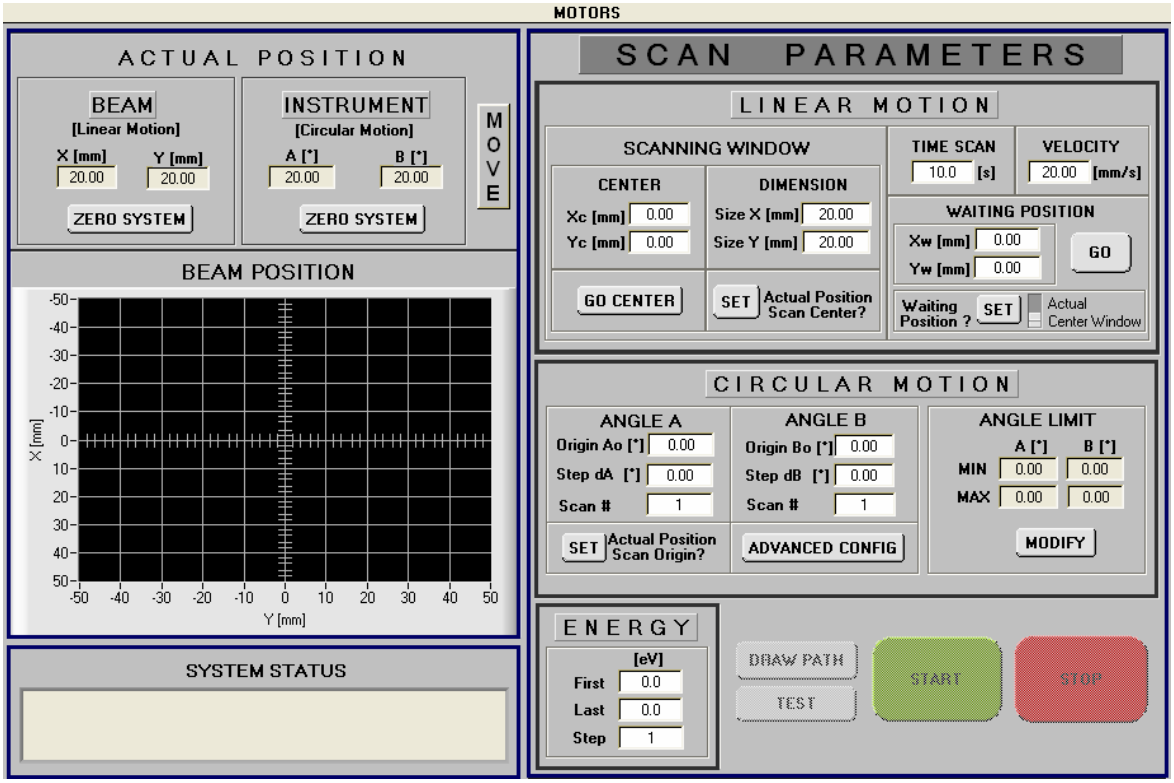


Figure 4.5 Main Panel

The user has direct access to the different variables of the system in the panel. The values of the variables were restricted to the physical limits of the system. The beam must stay inside a circle with a radius of 32 mm. Angles can rotate 360°, but precaution must be taken when an instrument is located inside the chamber, because the rotation angles will be limited. These two features are described in more detailed in Section 4.3.2.

When a scan needs to be executed, different system configuration needs to be taken into account. To conduct a scan three main subsystems variables need to be defined: linear motion, circular motion and the energy of the beam (added as an extra feature to the program). This division is found in the main panel to make system configuration easier for the user.

In the linear motion section definition of the movement of the beam can be configured. The scan window where the beam moves during a scan is defined by the center position of the window and its dimensions in length and width (20x20mm by default). The length of time during which the beam

remains in the same window throughout a scan can also be defined (10s by default). In addition, the speed of the motors can be altered. However this only applies to the motors with linear motion. Finally the waiting position of the beam while the system is changing the angles of the instrument during a scan can also be set. This waiting position can be set into the same position as that of the scanning window (by default).

For the circular motion configuration, different variables can be adjusted. The angles are limited according to the position of the instrument and cables inside the chamber, and also the layout of the detectors within the instrument is important. The start angle (scan origin), the increase of angle and the number of scans to be done during the scanning process can be configured for both angles. And finally for further development of the program an option was left open to have the possibility to allow for the possibility to define complex routines of angle changes. The velocity of the circular motion angles cannot be changed, as it remains at the default velocity of 2000 impulses per second all the time.

Finally the energy section allows the user to set the configuration of the different energies in the beam for the scan routine. As it can be seen the first, last and increment value can be modified.

Before launching a scan routine several actions need to be done. The DRAW PATH button has to be selected, and this will draw the path that the beam will follow when doing a scan. Then a test needs to be launched to be sure that the path followed by the beam is the one wanted. After this is done, a scan can be started. During a scan the motion can be stopped at any moment. For this, multiple threads were programmed.

In the following part the main task, of the developed program are presented.

4.3.1 The Movement of the Motors

Different functions were created for setting the variables for the motion of a motor. Functions for setting the velocity, the number of steps and the sense of the movement according to the desired position to be achieved, are programmed within the software. These variables are calculated within the PC software and then the values are sent by the COM2 port towards the IP28. After the configuration of the desired movement is done, a function (Move) sends the move command of the motors to the IP28 with the axis specification. The functions for configuring and moving the different motors are called in different subroutines of the developed software. The motors move relatively to the position in which they are located with a given number of steps towards a certain direction.

4.3.2 Scan Routine

The scan routine starts the motion of the motors with respect to the configured variables set by the user. Figure 4.6 shows the algorithm of the function where it can be seen that in hierarchy from first to last the

variables are modified as follow: linear motion, α, β and energy of the beam. Every time the variable has been cycled through all the values (first till last) the motors are positioned in their start/origin position.

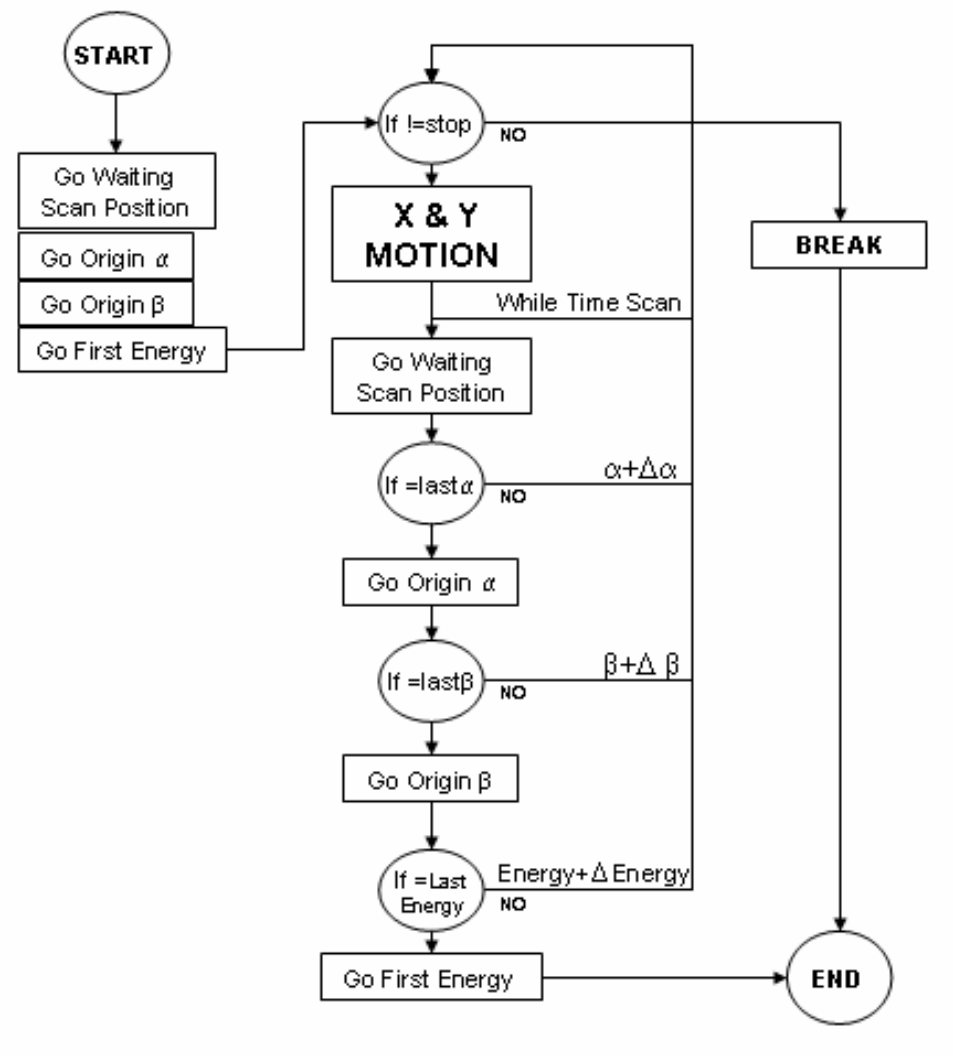


Figure 4.6 Scan Routine Algorithm.

This part of the program was added as an extra thread parallel to the main one, because it was necessary to give the user the option of stopping the routine during the scan. In order for the user to be able to stop the routine it was important that the interface could be accessed by the user all the times. If the software was structured with only one thread then the program would only be able to compute one task at a time. So multithreads were used to have the possibility of having two tasks running at once. Multiple threads can be executed in parallel on many computer systems. For the case of a single processor the system switches between different threads. This means that the process is not literally simultaneous [3].

The thread of the routine is configured from the very beginning of the program and it waits for a flag in order to start. This flag is given by the user when launching the scan with the START button.

The path of the scan is computed with the scan window limits and the beam surface. According to the length and width of the window the path is computed in straight lines as shown in Figure 4.7. The locations of each of

the corners is found for the way forwards and backwards, and then saved into an array that is called every time the path is scanned. The positions in the array set the values of the configuration of the lines written to the IP28 that will define the next movement of the motors. After a movement of a motor the actual position is read so the program checks that the desired position is achieved.

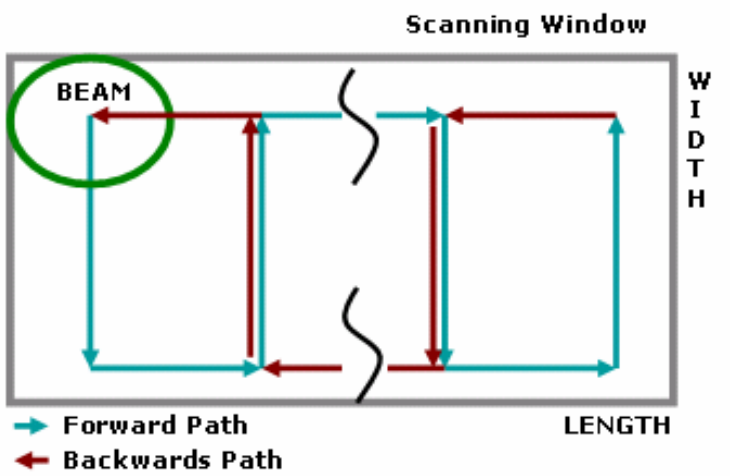
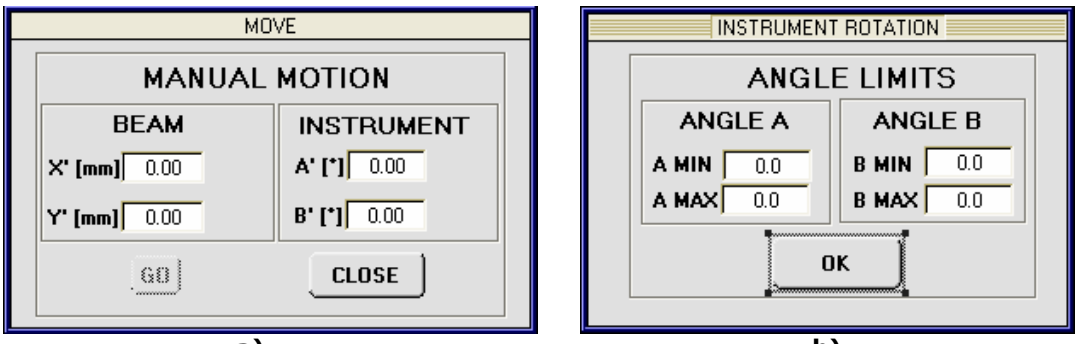


Figure 4.7 Scan Path Structure

4.3.3 Security Features

If a position needs to be changed a new window opens where the user can modify any of the motor positions. The option of having direct access to the position of the motors in the main panel was rejected in order to protect the system. This decision prevents any undesired movement of the motors which may have been caused by user errors. The manual motor motion window is presented in Figure 4.8 a).



a) **b)**

Figure 4.8 Manual Motion Panel (a) and Angle Limit Panel (b)

All of the variables of the positions can be modified, without changing the position of the motor. Motor position limits are established and therefore the user can not set a lower or higher value. When the desired position is given then by using the GO button the motors move. To disable the manual motion the window needs to be close.

Another security feature of the program is the ability to adjust the angle limits of the rotational motion depending on the instrument located in

the chamber. The angles limits are settled in a different window that can be opened by the user from the main panel. This window is always displayed at the beginning of the program as a configuration mode of the limits before any movement of the motors can be allowed. Figure 4.8 b) shows this window with the different variables that can be modified. After modifying the maximum and minimum values allowed and closing the window, the new limits will be displayed in the main panel.

4.4 LCPB – New Version

The integration of the two programs was done to be able to run them together and be able to get access to all the variables of the overall system at the same time. The different functions were kept, as well as the main panels and different sub panels of each of them. They were added together in the same 'main' of the program and the thread for the scan subroutine was also located inside it.

A start window was designed for the start of the program that shows the version and the developers of the different stages of the automation program. The start window is shown in Figure 4.9.

Figure 4.9 Start Window of the LCPB.

Finally the integration of the main panels of each of the two programs is shown in Figure 4.10.

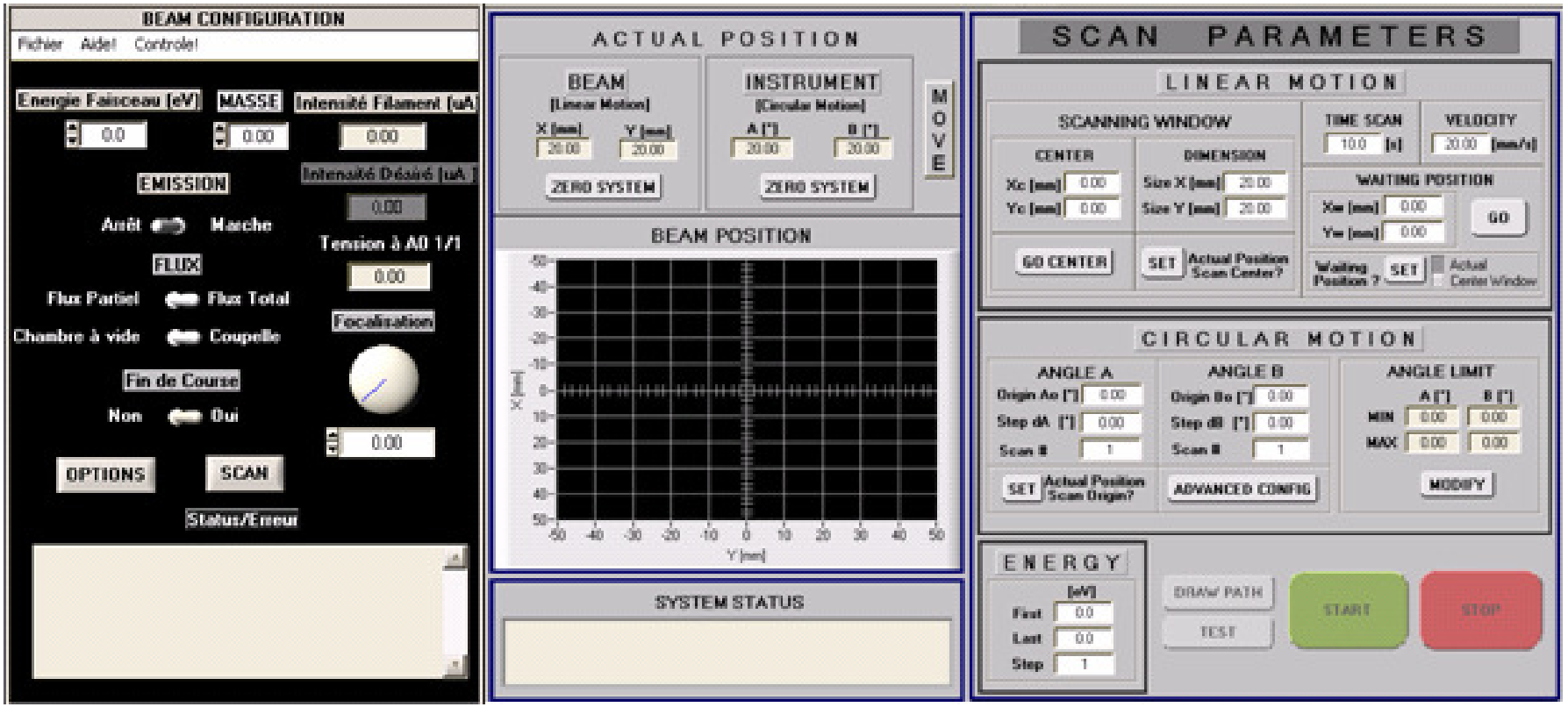


Figure 4.10 Integration System Panels.

5. CONCLUSIONS

The objectives were achieved. The program was tested with different configurations of the scan routine. The requirements demanded were achieved. The performance of the system was satisfying, but several features can still be developed to improve its performance.

One of the main problems that needed to be studied and understood was the serial communication between ports. Furthermore, it was essential that port communication was integrated into a system which did not produce any delay between the command of the user and expected response. The delays in the non-real time system were of several seconds, sometimes of just some ms, but this caused problems in the transmission. While the system was responding for some commands the PC was already trying to read from the port that was not ready. Delays had to be changed for reading the lines of the IP28, due to the slow time response of the motors. A computation of the delay time was integrated to the program, that according to the distance to be displaced and the motor speed the delay could vary.

The time consumed for studying the previous version of the LCPB was longer than expected, mainly because of the lack of a programmer guide of the algorithms of the program developed by other students. In order to avoid this same challenge in the future, the new part of the program which controls the motors was documented, thus making it easier to conduct updates to the program and improvements to any of the functions.

This is why the new part of the program that controls the motors was documented in case of that future work wants to be done to the program, or any improvement that wants to be done to any of the functions.

The study of multithreads and the implementation of one into the program also took time. It was important to understand the use of different variables (flags) to turn on/off the parallel thread of the scan routine, in order to avoid deadlocks. This part of the program can be improved by adding a thread that will allow the user to abruptly stop the motor at any moment desired, when any motion of motors is being done.

The development of this program was a major challenge for me. From a start with a lack of knowledge in several fields of the project, I ended learning a lot of new concepts that can be applied to different areas in engineering. It was really interesting to contribute to a project that has taken several years of different stages.

Further description of the Motors Command Software is included in the User Manual and Programmers Guide (Annex I).

6. FUTURE WORK

There are two main branches where future work can be done. The first one is related to the motors command program, where further development could improve its performance. The main points or areas where these improvements are recommended are listed below.

- Implementation of a save configuration that is being used, and import configuration option from last ones previously used. So if a calibration is not finished the position and set values for the different variables can be saved to a configuration file and that will be loaded back to continue from the stop point.
- Improve error detection. At the moment the error is only detected at the start of the program. If any error occurs while using the program most of the configuration should be reinitialized.
- Emergency stop at anytime the motors are moving and not only when the system is doing a scan.
- When the emergency stop button is used, the motor finishes its trajectory and then goes to the zero position. Implement the possibility of stopping the routine at any time and then as desired start again from the stop position or at the beginning of the routine.
- Disable the buttons from the IP28 panel when the user is controlling the motors directly in the user interface from the computer.
- Routine implementation for several sets of different angle increments for special layouts in the instrument that wants to be tuned.

The second branch of recommended improvements is related to the overall system. The work remaining to be done in order to achieve the complete automation of the system and also to improve features of the existing one are listed next.

- Implementation of a program to control the displacement of the ion detector.
- In the actual configuration the ion beam is checked sometime to ensure a good performance of the ion source. This could be done automatically after a certain number of scans, and saved to memory so it could be analyzed at the end of the calibration.
- Save the data from the different values of the system in a configuration file using a specific format.
- Understand the oscillation found in the filament current, every time the current is modified.
- Save the data when scanning the ions content of the beam.
- Save values of the variables in the old part of the LCPB in a file, and then create the possibility of importing them in order to configure the system.

7. GLOSSARY

Ion source: is an electro-magnetic device that is used to create charged particles.

Rhenium: chemical element with symbol Re and atomic number 75. It is a transition metal, and it is used in some alloys. Rhenium is obtained as a by-product of molybdenum refinement and rhenium-molybdenum alloys are superconducting. It is one of the ten most expensive metals on Earth. It has one of the highest melting points of all elements, exceeded by only tungsten and carbon. It is also of the densest, exceeded only by platinum, iridium, and osmium. Its usual commercial form is a powder. Widely used as filaments in mass spectrographs and in ion gauges.

Ion: atom or group of atoms, normally electrically neutral, that has lost or gained one or more electrons. The process of converting electrically neutral atoms or molecules into ions and the state of being ionized is called *ionization*. The recombining of ions and electrons to form neutral atoms or molecules is called *recombination*.

Anion: negatively charged ion, which has more electrons in its electrons shells than it has protons in its nucleus. It is attracted by the anode.

Cation: positively charged ion, which has fewer electrons than protons. It is attracted by the cathode.

Multi-threading: run multiple computation threads (tasks) in parallel in a system. Multithreads can be executed in parallel. There exist process resources sharing but the task are execute independently.

Deadlock: situation wherein two or more competing actions are waiting for the other to finish, and thus neither ever does.

8. REFERENCES

[1] Getting started with LabWindows/CVI. National Instruments Corporation. February 1998.

[2] LabWindows/CVI user manual. National Instruments Corporation. February 1998.

[3] Multithreading in LabWindows/CVI. National Instruments Corporation. July 2003.

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A1. ANNEX I

LCPB – Logiciel de Commande de la source du Petit Banc

LCPB

USER MANUAL & PROGRAMMERS GUIDE

VERSION - JUNE 2007

Maria Islas

CONTENTS

- **About This Manual**
- **Chapter 1 – Getting Started**
- **Chapter 2 – Motors Displacement**
- **Chapter 3 – Scan Routine Configuration**
- **Chapter 4 – Help / Feature Information**
- **Chapter 5 – Programmer Aid Guide**

About This Manual

The *LCPB User Manual & Programmers Guide* is a reference manual that contains detailed descriptions of LCPB new features and functionality. As an addition to this manual another document exists, *Documentation et Mode d'emploi du Logiciel de Commande du Petit Banc*, for the manipulation of the previous version software, which features are keep for the July 2007 LCPB version. The user should be familiar with both documents to be able to operate the overall system.

The LCPB User Manual explains the different tools of the LCPB software to manipulate the displacement of the system motors, and to configure different scan routines when tuning space instruments inside the vacuum chamber. For further information of the software and the test system refer to the thesis document *Study and Automation of a Test System for Space Instrument Calibration*.

This document is divided in five main parts where the LCPB new version software is documented. *Chapter 1* refers to the main steps in order to start the system and the different options to face possible problems that can be presented at this stage.

Two different situations were considered while developing the additional user interaction panel of the LCPB version 2007. The first one includes the displacement of the beam or the instrument manually to a defined position, or to their origin. The second one refers to the configuration and launch of a scanning routine to tune an instrument located in the chamber. These two operational modes were included in the user interface of the program. This main panel of the user interface is divided in two main sections that include all the features for these two operational modes. *Chapter 2* gives all the needed knowledge in order to interact with the main panel section that deals with the first operation mode (motors movement) mentioned above. *Chapter 3* is related to all the features of the second mode (configuration and launch of a scanning routine) that are found in the other section of the panel. *Chapter 4* refers to the aids that the software offers to the user while it is running. Finally, *Chapter 5* is a guide for any programmer that needs to get familiar with the software code in order to do any improvement or further development to the LCPB 2007 version.

1

Getting Started

In order to start the software the next options should be fulfill:

- IP28 should be connected to the COM2 of the PC via a serial RS232 cable.
- IP28 console must be turned on.
- TL78 console must be turned on.
- To avoid errors motors should be in the origin.
- The IP28 should be set to automatic mode (key on the right side of the console.

As soon as the LCPB software is started the communication between the PC and the IP28 is checked. If any communication error is found, a message will be displayed in the Motors panel and it is recommended to follow the next steps:

- Close the LCPB software.
- Check the serial connection.
- Check the location of the motors. The location should be a valid position of the system. If needed the motors should be located in the origin. The motors can be sent manually to the origin with the aid of the frontal panel of the IP28.
- Start again the LCPB software.

The four motors of the system (Figure 1.1) that can be modified by the new version of the LCPB software are the following:

- *Ion Beam displacement motors:* displacement along the x and y axis of the system. The displacement of these motors is restricted inside a circle of a radius of 32 mm.
- *Instrument inclination motors:* rotation along α and β. The rotation can be in both directions (clockwise or counter clockwise) a value of 360°. Special care needs to be taken when an instrument is located in the system due to the cables attached to it. In a scan routine set

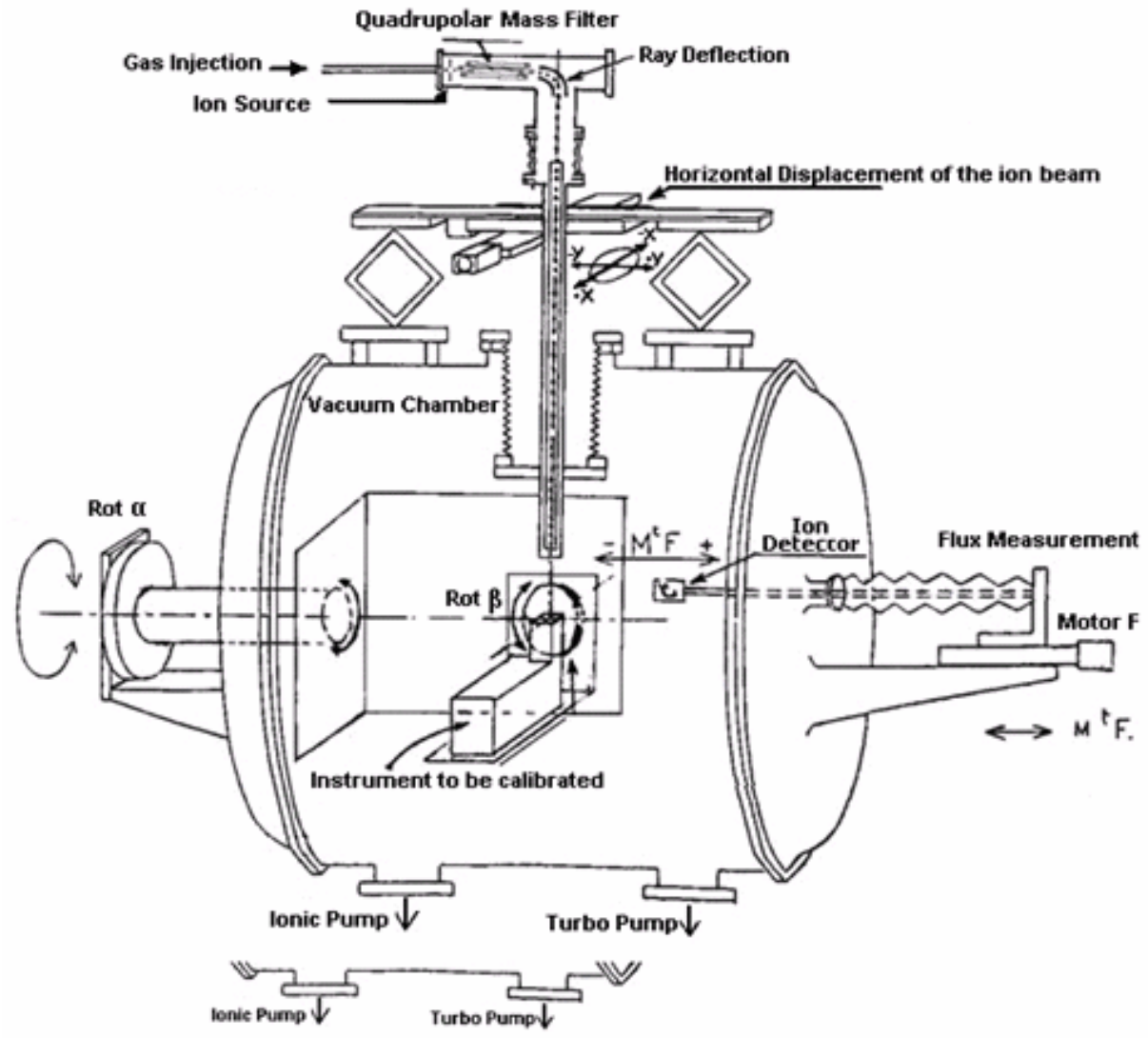

Figure 1.1 Low Energy Test Systems

by the user, α moves small values (scan in the same detection window of the instrument located in the chamber) and β moves bigger displacements (access to the different detector windows of the instrument).

For security reasons the limit of the angle displacements of the system must be set when starting the LCPB software. A window is automatically displayed when the software is opened. This window is shown in Figure 1.2. According to the location of the instrument in the chamber and its connection cables the user should select the maximum and minimum ranges where the angles α and β can be moved. By pressing the 'OK' key the limits will be stored in the program. The selected values will be displayed in the main panel. Future modification of the angle limits can be accessed from the main panel of the software.

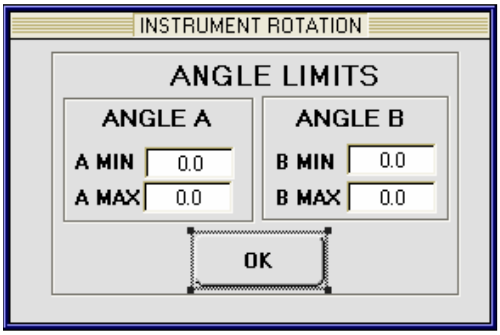

Figure 1.2 Angle Limit Panel

The default values of the system variables when starting the software are displayed in the main panel. The speed of the motors is set to a default of 2000 impulses/seconds.

2

Motors Displacement

As mentioned before the motors main panel added to the LCPB software is divided in two main sections according to the tasks that the users needs from the system. In this chapter the Motors Displacement Section is described.

In Figure 2.1 the motors displacement section of the panel is shown, while the other section is covered. As it can be seen in the figure this section is at the same time divided in different subsections: *Actual Position*, *Beam Position* and *System Status*.

The *System Status* Subsection that is located at the left bottom of the LCPB panel. In this area, messages are displayed to the user in case of being needed. When the software is started a 'SYSTEM IS READY' message will let the user know that the system can start to be manipulated. Errors of the system are also displayed in this area.

The *Beam Position* Subsection, located in the middle of the Motors Displacement Section, includes a graph. In this section the actual position of the ion beam in the system is drawn. This is should help the user to get an idea of where is the beam (green circle of 10mm radius) with respect to the system limits (yellow circumference of 32mm radius). Anytime the beam is moved, the draw of the new position acquired by the beam will be displayed. Only the final destination of the movement will be shown, i.e., not real time drawing is done. At the end of each partial movement (each motor axis) the actual position is read and displayed in the graph.

The *Actual Position* Subsection, located at the right top of the panel displays the real position in millimeters of the motors with respect to the zero of the system, and gives the user the option of different movements of the motors.

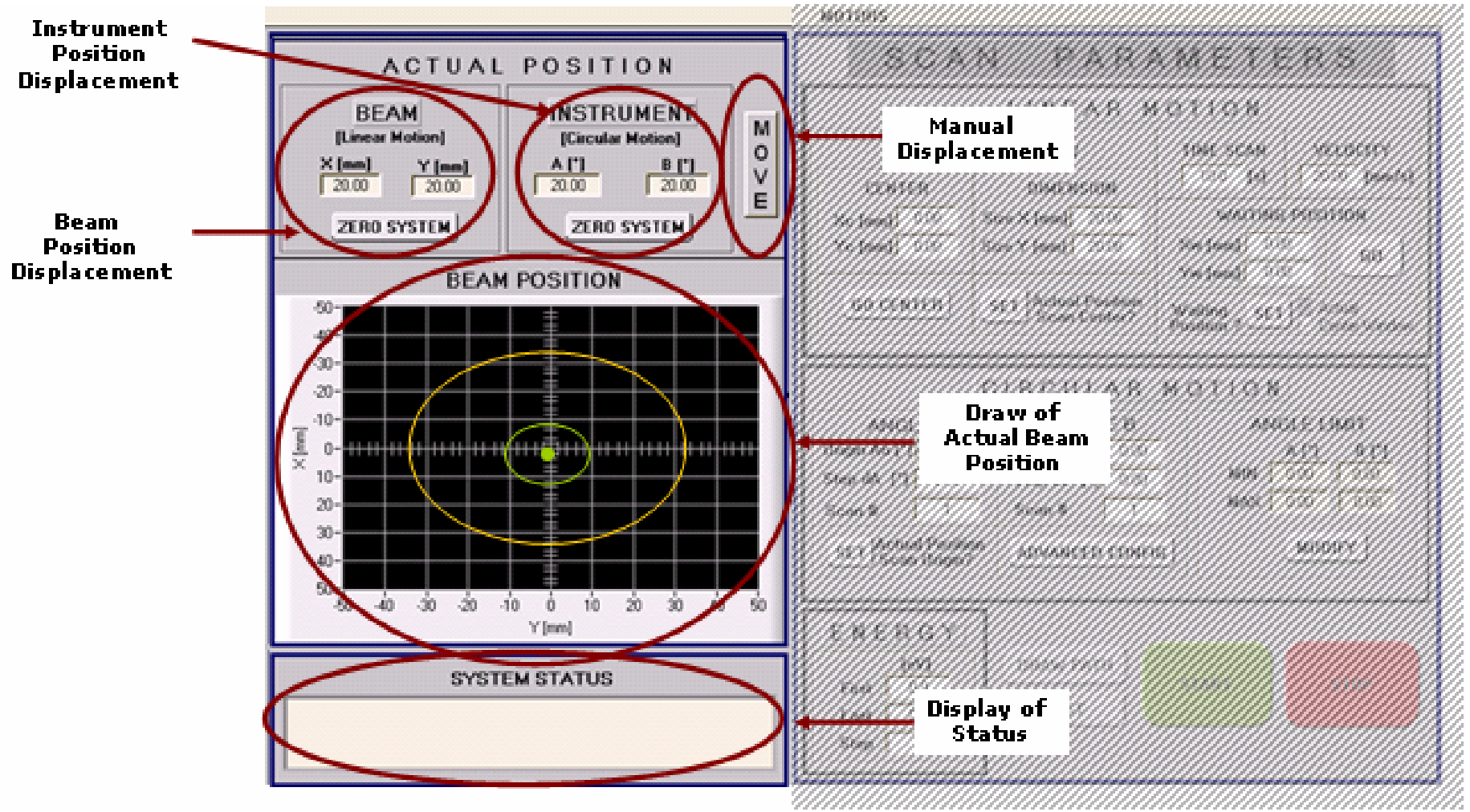

Figure 2.1 Motors Displacement Section

This subsection is split in three areas which are explained next. First the position of the *Beam* can be found (Figure 2.2). The Beam is located with respect to the x and y axis of the system. After any movement of the motors, the position values will be updated. A 'ZERO SYSTEM' button can be press if the beam wants to be sent to the system origin.

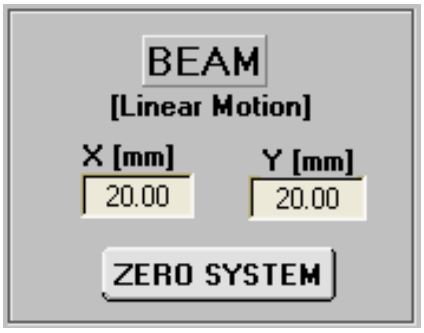

Figure 2.2 Beam Position Area

The next area (Figure 2.3) is related to the Instrument location inside the chamber in relation to the α and β motors angles. As it is done for the beam, the values of the instrument position are updated every time a movement has been done. Here the 'ZERO SYSTEM' button also sends to the system origin the angular motors. Be aware that every time the system is sent to zero it will check if the zero position is located inside the angle limit ranges. If the zero position is not located within the ranges this movement will not be allowed.

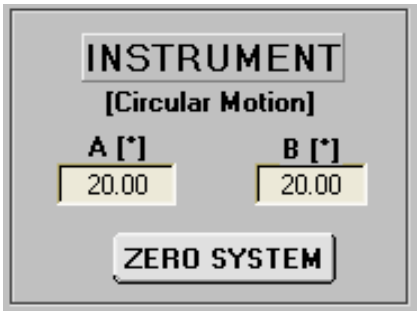

Figure 2.3 Instrument Position Area

If a desired manual movement wants to be done to the motors, then the 'MOVE' key (Figure 2.1) located at the top left of the Motors Displacement Section should be pressed. This action will open a new window that will allow the user to manually move the motors of the system. The use of a separate window for manual displacement of the motors protects the

system for any unwanted user action. The motors displacement will not be accessible by the user but only by selecting the 'MOVE' key and the new window is displayed. Another way of accessing the displacement of the motors is done in the Scan Routine Configuration Section, but this will be explained in Chapter 3.

The Manual Motion Window (Figure 2.4) will allow the user to give a desired value of the position that wants to be achieved. The value given by the user will be checked with respect to the system limits. If the values are out of the limits an error message will be displayed and a new value will be asked from the user. When the values given by the user are correct, the 'GO' button will be accessible and by selecting it the beam and the instrument will move to the selected position. For closing the window, the 'CLOSE' key should be selected.

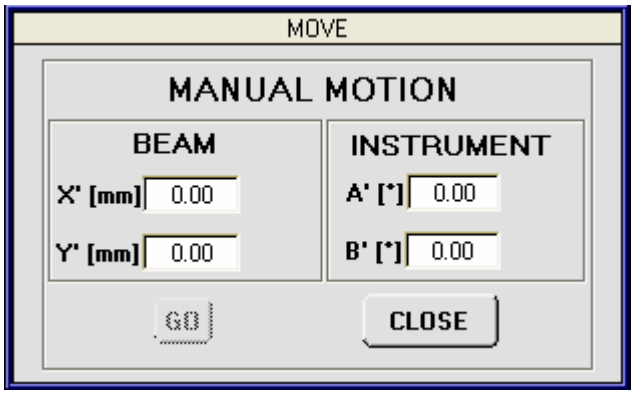

Figure 2.4 Manual Motion Window

3

Scan Routine Configuration

The scan routine configuration is done on the right half of the motors panel. As shown in Figure 3.1 the Scan Routine Configuration Section is divided in different areas or subsections. To set the parameters of a scan routine, three main fields must be defined and these can be found in this section: parameters of the linear motion, parameters of the circular motion and finally the parameters of the beam energy. At the right button of the panel the area to launch of the routine is found.

3.1 LINEAR MOTION PARAMETERS

For the linear motion parameters different variables can be modified. These variables are listed below:

- *Scanning Window*
    - *Center:* x and y position of the center of the scanning window.
    - *Dimension:* x and y size of the scanning window, length and width of the window area.
- *Time Scan:* Time that the beam will stay scanning the same scanning window, following a defined path computed from the scan window surface.
- *Velocity:* Motors speed in any linear displacement. If the speed is changed this new speed will be used also when a manual movement of the motors is done.
- *Waiting Position:* x and y position of a waiting position while angle displacements are done to turn the instrument in the chamber.

In addition to these variables which values can be changed according to the need of the user, different keys are also found in the Linear Motion Subsection. The different functions of these buttons are explained next.

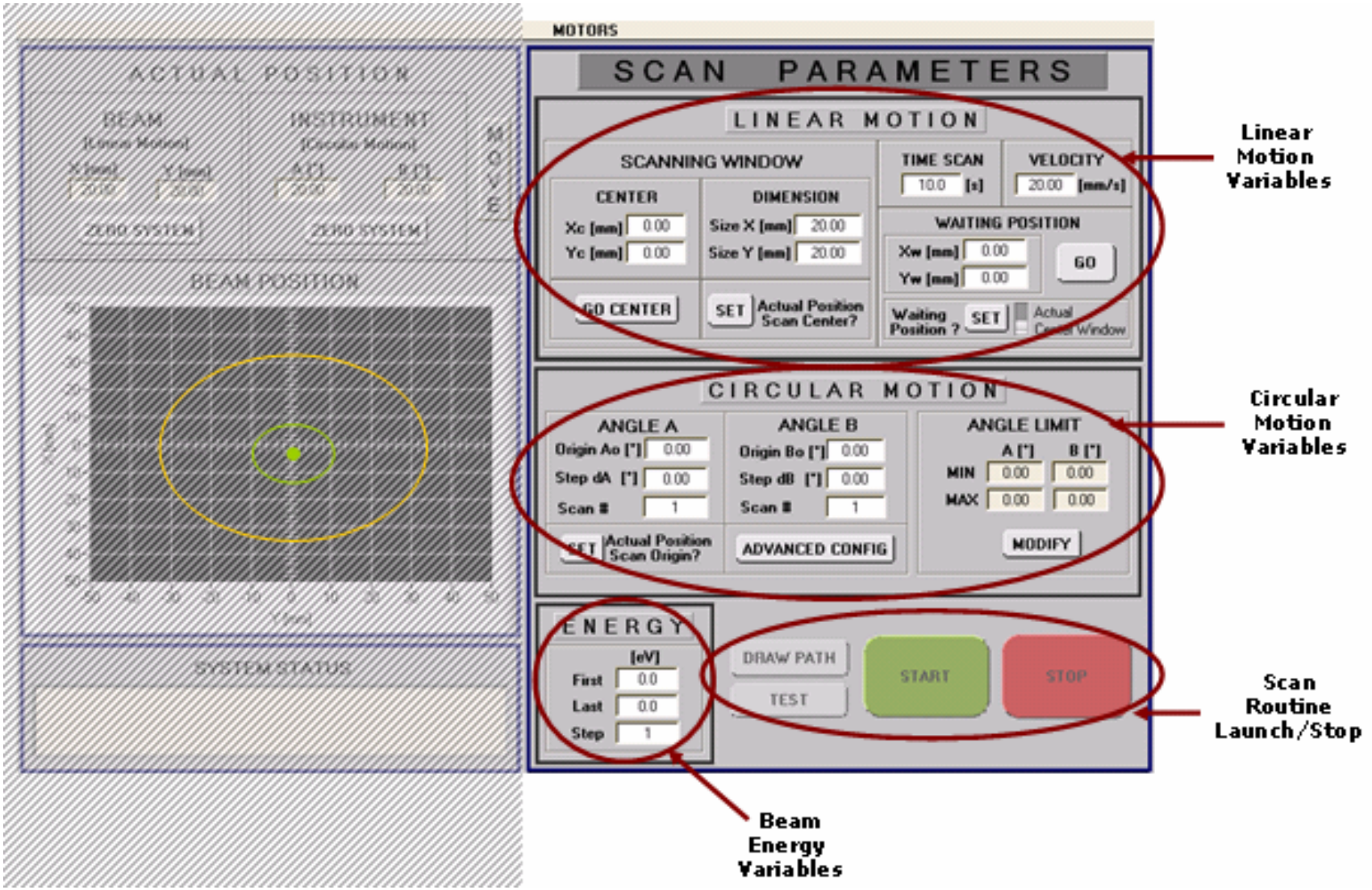

Figure 3.1 Scan Routine Configuration Section.

- *GO CENTER:* Takes the x and y motors to the defined center position. If the motors are already located in the center position, no movement will be done.
- *SET Actual Position as Scan Center:* Sets the position where the motors are located as the center of the scanning window.
- *GO:* Takes the motors to the defined waiting position.
- *SET Waiting Position:* Sets the actual position of the motors or the center of the scanning window as the waiting position. This is selected from the switch located in the right side of the button.

As the user defines these parameters the scanning window is drawn in the Beam Position Graph, as an aid for the user. It is important to notice that the size of the window should consider that the center of the beam can not go further than a circle of 32 mm radius, that it is always displayed in the plot area. Considering this is needed when defining the scanning window. The beam will never touch the corners of the scanning window due to its circular form.

3.2 CIRCULAR MOTION PARAMETERS

For the circular motion parameters different variables can be modified. These variables are listed below:

- *Angle A*
    - *Origin A_o:* α start position for a scan routine.
    - *Step dA:* α increment after every linear scan over a determined scanning window.
    - *Scan #:* number of times the α increment will be done during a scan routine.
- *Angle B:* same as before but applied for the β rotational motor.
- *Angle Limit:* This area is only for the display of the angle limits if a modification of the values wants to be done the 'MODIFY' key needs to be press to display the Angle Limit Window.

In addition to these variables which values can be changed according to the need of the user, different keys are also found in the Circular Motion Subsection. The different functions of these buttons are explained next.

- *SET Actual Position as Scan Origin:* Sets the position where the motors are located as the origin of the scan routine.
- *ADVANCED CONFIG:* Opens a new window where a complex angle step configuration can be defined (this area needs further development).
- *MODIFY:* Opens a new window where the angle limit ranges can be changed by the user (Refer to Chapter 1).

3.3 BEAM ENERGY

For the beam energy parameters different variables can be modified. These variables are listed below:

- *First:* Sets the value of the energy at the start of the scan.
- *Last:* Gives the last energy value that will be achieved at the end of the scan routine.
- *Step:* Gives the energy increment that needs to be done between each scan subroutine.

Every time a modification to the energy is done the panel of the ion beam parameters is also updated. At the end of each scan routine the energy goes back to the first beam energy.

3.4 LAUNCH SCAN ROUTINE

Different keys are available for the user in order to launch or stop a scan routine. Due to safety reasons, the 'START' key is disable until the path follow for the scan is drawn (press 'DRAW PATH') and a test is also run (after drawing the scan surface press 'TEST'). This will allow the user to make sure the set parameters for the linear motion can be done by the system.

After the start of a sequence is done, the 'STOP' key becomes available. The scan routine can be at any time stopped by the user. If the 'STOP' key is selected, the last movement of the motor will be finished and the program will take the beam to the waiting position, the energy of the beam to the first value and the instrument to the starting angles.

4

Help / Features Information

While using the LCPB new developed panel, direct aid for the user is available. If the user needs information for any of the features located in the panel, a right click of the mouse over the feature will display a message with the specific information of the variable or button selected.

The values of all parameters that can be set by the user are always checked by the system in order to avoid errors. If a wrong value is introduced an error message will be displayed and the system will set in the variable the previous system value. The error message will tell the user the value characteristics expected for the variable that presents the error. Value limits, number ranges, system limits are established in software code.

Before any motor displacement is done the system checks the parameters given by the user to avoid errors. Double or even triple value error check is done as a protection of the system.

5

Programmer Aid Guide

This section was thought as an aid for future programmers that will need to get familiar with the code of the new version of the LCPB added to the previous version. For basics in the IP28 – PC communication please refer to the Section 4.2 of the thesis document *Study and Automation of a Test System for Space Instrument Calibration*. In this Chapter an overall description of the functions added to the code is included as well as the distribution of the main variables for the motors.

The IP28 names each of the motors with the next group of variables: W, X, Y and Z. For simplicity in the new developed software the variables are called as the scientist at the CESR named them and recognize them. Table 5.1 presents the correspondence of the variables inside the IP28 with respect to the variables of the Middle Energy Test System presented in Figure 1.1. The LCPB code uses the variable names presented in the second column from the table when interfacing with the user, while it writes and reads from the IP28 (through COM2) with the variable names found on the third column.

System variable	LCPB variable	IP28 variable
X	X	X
Y	Y	Y
α	A	W
β	B	Z

Table 5.1 Correspondence of variables.

The functions developed for the software code are listed below with a brief explanation of their main tasks. The functions are listed in group according to their application and in alphabetic order.

- Functions that QUIT different user interface windows:
    - *ANGLES:* Function that QUITS the panel of angle limits. When closing it will check if the angles are located inside the limit

values, if this is not true an error message will appear and the user will be ask to set the limits again.

- *MANUAL:* Function that QUITS the manual move panel. If the desired positions are not the actual positions of the motors a warning message will be sent to the user.
- *MOTORS:* Function that QUITS the program. It sends the motors to the origin before closing the program and also close the thread, of the multi task.

- Functions that take the motors to the system origin:
  - *GOORIGINBEAM:* Function that takes the motors X and Y to the zero position of the system. Sends to zero, saves the values, displays the value and plots in the graph the new location.
  - *GOORIGINSTRUMENT:* Function that takes the motors A and B to the zero position of the system. Sends to zero, saves the values and displays the value.
- Functions for the manual motion of the motors (Manual Motion Window):
  - *DONEMANUAL:* close the Manual Motion Window.
  - *GOWANTEDPOSITION:* takes the motor to the desired positions. Checks that the beam stays inside the circle of R=32mm and the instrument inside the angle range limits.
  - *MANUALPOSITION:* Opens a panel that lets move the motors to a desired position.
  - *xxxWANTED:* Gets the desired position to move the motors. Checks the position given for the desired position to be inside the limits (Applies for the four motors).
- Functions that configure the parameters of the linear motion (Beam Motion):
  - *GOCENTERSCAN:* Moves the motor to the Scan Surface Center configured in the user interface. If the motors are already located in this position they will not move.
  - *GOWAITINGPOSITION:* Takes the motors to the waiting scan position.

  - *LINEARVELOCITY:* Sets the velocity of the motors for the system for linear motion. Checks the boundary conditions for the velocity and selects from fast/slow speed.
  - *SETCURRENTSCAN:* Gets the actual value of X and Y and use it as the value of the Scan Window Center.
  - *SETWAITINGPOSITION:* Sets the Actual Position or the Window Center as waiting point during the rotation of angles in the scan routine.
  - *SIZExxx:* Defines the X and Y lengths for the Scan Window.
  - *TIMESCAN:* Sets the time that the scan will be done in a same Scan Window before rotating the instrument.
  - *WAITINGPOS:* Gives the X and Y position for waiting during rotation of angles in the scan. Checks that the beam stays inside the circle of R=32mm.
  - *xxxCENTER_SCAN:* Sets the center position for the Scan Window. Checks that the beam stays inside the circle of R=32mm (Applies for X and Y motors).
- Functions to set the angle limit ranges (Angle Limit Window):
  - *SETANGLELIMITS:* Sets the value of the angles and goes back to the main panel. Check parameters so they stay inside the limits.
  - *xxxLIMIT:* Gives the MAX and MIN limits for the displacements of each angle. (Applies for A and B)
  - *xxxMINMAX:* Gets the value for the maximum and minimum angle for the scan routine for A and B.
- Functions that configure the parameters of the circular motion (Instrument Motion):
  - *ADVANCEDCONFIG:* To configure a routine with different angle steps for different sectors (Not developed yet).
  - *SETCURRENTORIGIN:* Gets the actual position and use it as the scan origin for A and B.

- *xxxORGIN_SCAN:* Sets the angle position for the Scan Origin. Checks that the values are between the limit of the angles (Applies for A and B motors).
- *xxxSCANNUMBER:* Number of displacements to be done in each angle. Check parameters so they stay inside the limits (Applies for A and B motors).
- *xxxSTEP:* Gives the increment value of the angle during the scan. Check parameters so they stay inside the limits (Applies for A and B motors).

- Functions that configure the parameters of the energy in the beam:
  - *FIRSTENERGY*: Sets the starting energy for the scan routine, and sends the value to the system to adjust the energy on it.
  - *LASTENERGY*: Sets the last energy for the scan routine.
  - *STEPENERGY:* Sets the step for the increase in energy for each subroutine.
- Functions to prepare, launch and stop the scan routine:
  - *DRAWSCAN:* Gets the path and simulates the scan. Needs to be launch before starting the scan to be sure the scan path is correct.
  - *START:* Starts the Scan with the parameters determined by the user. It calls a thread where the routine is computed.
  - *STOP:* Emergency stop during the scan routine. It sends the flag for stopping the routine in the thread.
  - *TEST:* Makes a simulation of the path of the beam through the scan window (x and y direction). Moves the beam from the actual position to the waiting scan and then starts the scan. At the end the beam goes back to the waiting scan position. This function needs to be used before being able to launch a full scan routine.
  - *THREAD_1*: Waits for the launch routine variable to be activated to start the cycle.

- Other functions:
    - *CHECKANGLELIMIT:* Checks that the angle parameters for the scan routine remain inside the angle limits settle by the user.
    - *DRAWPOINT:* Draws the position of the beam in the x/y graph.
    - *DRAWSCANPATH:* Draws the trajectory that the beam will follow through the scan window.
    - *DRAWSCANSURFACE:* Draws in the graph the scanning window.
    - *GETPOSITION:* Asks the interface for the position of certain motor.
    - *GETSCANSURFACE:* Gets the values of the corner of the scanning window.
    - *GOPOSITION:* Takes motor X and Y to a desired position. Checks which motor to move first so it does not go out of the limited circle of R=32mm.
    - *MOVE:* Writes to the console to move the motor with certain axis. The parameters of the motion were already defined by the other function.
    - *READPORT:* Reads from the port COM2 the waiting message, takes the needed part of the line, and trashes the other remaining part.
    - *SCANNINGPATH:* Gets the trajectory to follow for the x/y motion.
    - *SEARCHORIGIN:* Looks for the axis origin of the required motor.
    - *SETPARAMETERS:* Configures the parameters of motion. Writes to the console the direction and number of steps a motor with certain axis should move.
    - *SETVELOCITY:* Sets the velocity of the motion.